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CONTENTS

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ABSTRACT
[Confidential]

A high-resolution radar system (0.008-microsecond pulse length), operating at 3-cm wavelength, has been used in oceanographic studies from a coastal site. Sea return clutter amplitudes are presented from A-scope data recorded on 16-mm motion picture film. System parameters and data reduction methods and equipment are outlined.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem R07-17
Projects NR 412-000, NR 412-003, NR 430-014-1,
NO 061-631, and NE 050-416
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[redacted]

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HIGH-RESOLUTION RADAR
PART II - SEA CLUTTER MEASUREMENTS
[Unclassified Title]

INTRODUCTION

This report is one of a series in the study of sea return with high-resolution radar. It presents the results derived from a photographic method of data recording.

Sea return clutter measurements were made with an experimental, high-resolution, X-band radar system from a coastal site at Boca Raton, Florida, during the period of October 1955 to December 1955.

The experiments were conducted to investigate the characteristics of high-resolution radar echoes as they pertained to sea return. The variation of signal amplitude with polarization, range, azimuth angle, antenna height, sea condition, and wind speed and direction were essential factors to be considered in the tests.

This report presents some of the results obtained from the analysis of A-scope photographic data.

LOCATION

The test site on the east coast of Florida at Boca Raton afforded relatively deep ocean depths at short range as shown in Fig. 1.

The radar antenna was mounted on an elevator platform suspended from a steel tower 100 feet high (Fig. 2). This platform could be varied in height from 27 feet to 113 feet above the sea level. Its coverage was more than adequate to embrace the ocean area under surveillance. Vertical depression angles as great as six degrees were possible.

The view toward the sea by the radar antenna was unobstructed from 5 degrees to 170 degrees true bearing.

The prevailing winds in this area are usually from the east. It was hoped (in vain) that extreme conditions of sea and wind would be encountered during one or more days of the test period because of the normal "huricane season" expected at that time in that area.

The average tidal change at this location was about three feet.

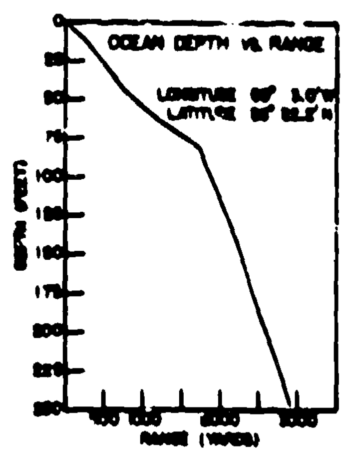

Fig. 1 - Ocean depth versus range

[redacted]

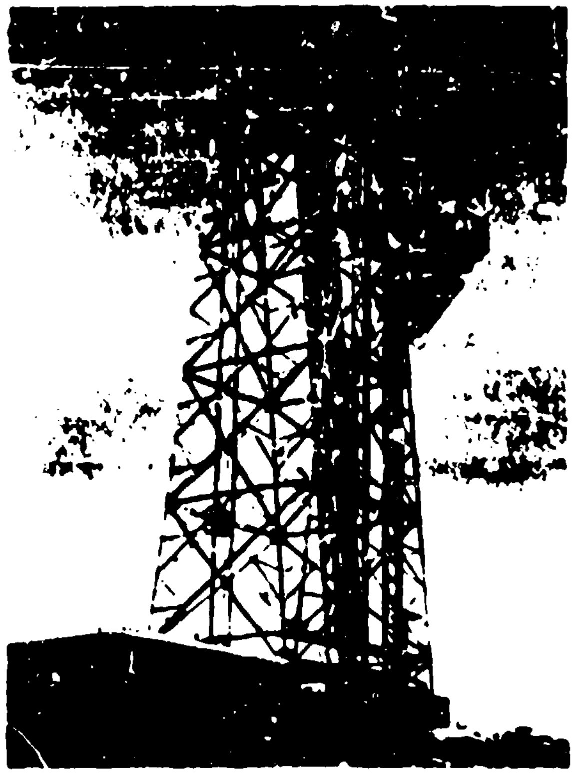

Fig. 2 - Elevator platform and tower

RADAR SYSTEM CHARACTERISTICS

Listed below are some of the pertinent characteristics of the experimental radar system used in the measurements:

Frequency	9375 Mc
Transmitter Power (Peak)	15 kw
Pulse Length	0.008 μsec
Pulse Recurrence Rate	1800 cps
Receiver Noise Figure	25 db
Polarization	vertical or horizontal
Antenna	8-foot parabola
Antenna Beamwidth	0.9°
Video Bandwidth	100 Mc
I-F Passband	2500 to 2700 Mc
Display	A- or B-scope

The antenna, transmitter, rf amplifier, and mixer were located on the movable platform and the i-f and video amplifiers, timing, display, and recording equipment located in a U. S. Navy trailer van positioned at the base of the radar tower.

AUXILIARY EQUIPMENT

There were two additional pieces of equipment used in these experiments to acquire supplementary data:

1. An [illegible]/UMQ-5 wind measuring and recording system was used to acquire meteorological information. The vane and anemometer were mounted atop the radar tower at a height of approximately 125 feet above sea level. The visual indicators and the simultaneous automatic recorder were located in the radar van. The recorder chart provided a continuous log of the wind speed and direction for each twenty-four hour period.

2. An ocean wave-height measuring gage of the step resistance type, which was developed by the Beach Erosion Board, was located at a range of 450 yards from the test site and at a bearing of 95 degrees. It was mounted on a piling driven into the ocean floor where the depth of the water was approximately 25 feet. Automatic, as well as manual, control of the wave gage permitted convenient monitoring of wave height. A Brush recorder located in the radar van provided permanent records of this information. Wave-height information was automatically registered on the chart paper for periods of two minutes of each hour of every day. This sample portrayed the sea-state condition and tended to indicate the prevailing trend. During data taking periods, the wave gage recorder was frequently run under manual control to acquire coincident wave and radar information.

MEASUREMENT METHODS

This report presents the results derived from A-scope data on sea return clutter, as recorded on 16-mm motion picture film.

A modified Bell and Howell, 16-mm, magazine-load, motion-picture camera was used to photograph the radar video output on a delayed A-scope display under the following conditions:

Camera Speed	8 frames per second
Shutter	130°
Exposure Time	1/16 sec
Film	Kodak TRI-X
Lens and Aperture	1" - f2.7
CRT Phosphor	P-11

Each fifty-foot film magazine was identified at the beginning of the reel by projecting, via a mirror, a semiautomatic data-recording board onto the film.

The basic reference of radar area used in these measurements was obtained from a balloon-suspended, metal sphere, flying under free-space conditions. The radar reflection area of this sphere was 0.018 square meter.

Because the use of such a sphere was not convenient nor feasible for all periods of the radar system operation, a corner reflector was, therefore, used as the standard echoing area throughout the tests. This corner reflector was designed and constructed for a reflection area of 93 square feet under free-space conditions and when measured as located with the metal sphere as the computation base, an echoing area of 360 square feet was realized. The corner reflector was located on the beach at a range of 1340 yards and was approximately 9 feet above the ground level.

The performance and stability of the radar system was monitored at the beginning and end of each data-recording period for both horizontal and vertical antenna polarizations with this corner reflector as the standard echoing area. Reference information and power calibration of the radar system was photographed at frequent intervals during the data runs using the calibrated output from a Hewlett-Packard, Model 620A, signal generator.

With this combination of the corner reflector standard signal and the film-recorded, radar-system power calibration, the sea-return echo area was computed in square feet. The peak power received from the corner reflector is given by

$$P_c = \frac{P_t G^2 \lambda^2 \sigma_c}{4\pi^3 R_c^4}$$

where

P_t = Peak transmitter power

G = Antenna gain

λ = Transmitter wavelength

σ_c = Corner reflecting area in square feet

R_c = Range to the corner.

The peak power received from the sea clutter is

$$P_w = \frac{P_t G^2 \lambda^2 \sigma_w}{4\pi^3 R_w^4}$$

with

σ_w = Radar area per sample of sea clutter (sample length, 1/15 sec; sample rate, 5 per second)

R_w = Range in feet to sample area.

By dividing P_w by P_c

$$\frac{P_w}{P_c} = \left(\frac{\sigma_w}{\sigma_c}\right)\left(\frac{R_c}{R_w}\right)^4$$

or

$$\sigma_w = \left(\frac{P_w}{P_c}\right)\left(\frac{R_w}{R_c}\right)^4 \sigma_c$$

In this equation,

$\frac{P_w}{P_c}$ may be measured by comparison with signal generator (HP-620A);

$\left(\frac{R_w}{R_c}\right)^4$ is obtained from radar data;

σ_c is the corner reflector area as located 360 ft².

To obtain a unit radar area:

$$\sigma_0 = \frac{\sigma}{R \theta \tau}$$

where σ_0 = Echoing area per unit area

R = Radar range in feet

θ = Antenna beamwidth in radians

τ = Equivalent transmitter pulse length

In presenting the results $10 \log_{10} \sigma_0$ is plotted versus several parameters.

OTHER MEASUREMENTS

Movie cameras were located adjacent to the radar antenna on the movable platform and atop the steel tower for simultaneous visual photographs* of the radar area under surveillance. These cameras were equipped with telephoto lenses whose focal length was chosen to give an azimuth angular coverage as close to that of the radar antenna beamwidth as possible. The operation of these cameras was electrically synchronized to that of the scope data camera.

Azimuth scan of the antenna waveguide feed provided facilities for a B-scope presentation on the radar indicator. Synchronized, impulse-operated cameras, triggered at the antenna-scan motion extremities, were used for the data recording of both the radar indicator and the visual information.

Other methods of data recording employed during these experiments were the use of a Fairchild 35-mm continuous-film camera for sampling of the radar clutter amplitude at the radar-recurrence frequency and a Brush recording-pen system for radar-signal measurements of very short range segments. These latter systems are discussed in a separate report.

DATA PROCESSING

To facilitate extraction of the data portrayed on the 16-mm motion picture film, a film reader was designed and constructed which, when used with suitable counting units, provided a simple and quick method for data readout.

The use of small phototransistors as the sensitive elements in the film reader permitted the film-projection distance to be approximately 24 inches. The size of the projected image at this distance was approximately 4 inches wide by 3 inches high.

*The use of the words "visual photographs" in the text of this report refers to outdoor photography that is recorded of the area which the radar antenna would "see" from an optical viewpoint. This serves to differentiate it from the other and more specific data recording photography of the radar-scope traces.

A total of 16 phototransistors (WE 1740) were mounted side by side in a holder attached to a 4-inch by 3-inch projection surface. A 1/32-inch slit cut through this surface allowed the most sensitive portion of each phototransistor to be exposed. This created a sensitive slit 1/32 inch wide by approximately 2 inches long for the 16 elements.

About 1.2% of the total range sweep was resolved through the 1/32-inch slit and the radar echo amplitude could be monitored at any one of the 16 levels represented by the 16 adjacent photocells.

Shown in Fig. 3 is a sketch of the photocell holder and projection surface in which "A" represents the sixteen cells positioned side by side with the 1/32-inch slit allowing a portion of the sensitive area to show through. By individual adjustment of each photocell, the most responsive portion of the photocell window was positioned in line with the slit.

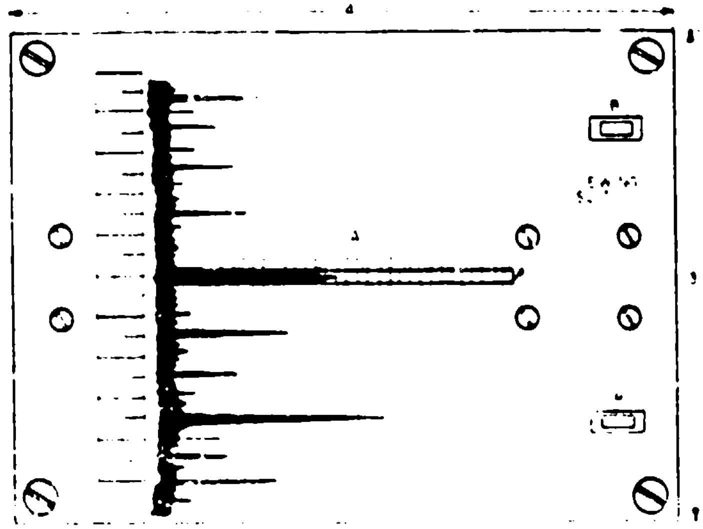

Fig. 3 - Photocell holder

The photocells as indicated by "B" served to de-energize the reader during the projector shutter time, as well as to compensate for variations in film densities.

In the figure "C" represents a typical, projected, A-scope, sea return, radar trace. When an echo interrupted the projected light falling on a particular photocell a pulse was generated, its cell position identifiable by its width. If an echo should be received of an amplitude to interrupt the eleventh cell, for example, all cells up through eleven would be energized. However, by the use of a suitable mixing process, only the widest pulse was used to actuate the decade-counting and tabulating circuit. Thus, the film reader was used to count all echoes which were equal to or greater than a preset level as determined by the position of the selected photocell.

The particular photocells monitored for each data run were selected by first projecting the system calibration run onto the reader. As the calibration run was made in 3-db steps, the dynamic range of the system would indicate some five to seven cells to be monitored.

From the information gathered with this system, curves were drawn of the percentage of time that the echoes at some particular range were at least equal to the signal level in db from the calibration curve. This basic data was then extended to portray the information shown in the Appendix.

The data presented was extracted from delayed, CRT sweep lengths of 250 yards. The majority of the information was acquired in one-minute data-recording runs, though a few data runs of two minutes duration were available.

PRESENTATION OF RESULTS

Listed below is a short description and sequence of the graphical analysis derived from the A-scope photographic data reduction. The graphs are presented in the Appendix.

I. σ_0 versus declination angle in degrees for signal returns of 2% to 15%.

II. σ_0 versus percentage of time for three wind speeds.

III. σ_0 versus percentage of time for three antenna heights.

IV. σ_0 versus percentage of time for into-the-trough and into-the-waves of three antenna heights.

V. σ_0 versus declination angle in degrees for two wave heights.

VI. σ_0 versus declination angle in degrees for three wind speeds.

VII. σ_0 versus wind speed for signal returns of 2% to 15%.

SIGNIFICANCE OF RESULTS

No attempt is made in this report to evaluate the significance of the results of the work presented, since it is planned in a subsequent report, in this series on high-resolution radar studies, to show comparisons with longer-pulse radar systems and other work in the field.

• • •

APPENDIX
Graphs of Results

In Figs. A1 through A4 and Figs. A15 and A16, the shaded boundaries of the plot indicate a σ_o variance from 2% to 15%. To state this in other words: the upper limit of the shaded section indicates σ_o values for 2% of the total data sample and the lower limit of the shaded section indicates σ_o values for 15% of the total data sample.

In Figs. A5 through A10 σ_o is plotted versus the percentage of time that it equals or exceeds a particular value of σ_o. For example, at a point of 30% in Fig. A6 and at a wind speed of 16 knots, the graph indicates that with vertical polarization we may expect σ_o to be -32 db or less for 30% of the time.

The composition of these graphs is a result of an averaging of many points, and the lines closely follow and portray the trend of the basic data

The values indicating wave height for each graph were extracted from the wave-gage records. The value selected was the "third high" value prevailing in the wave-height-period sample nearest in time to the photographic radar data.*

The declination angle [illegible] as indicated in the graphs is that angle whose tangent is indicated by the quotient of the height of the antenna above average water to the range of the target.

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*According to the Beach Erosion Board procedure for analysis of wave-gage data, the time in seconds of the wave period of the data indicates "approximate significant wave heights" as the "third highest." Therefore, the wave amplitudes were tablulated from the recorded data and the third highest value selected as the representative one to be used in the report

1. -, Versus :

Figures A1 through A4 show the -, plotted versus declination angle in degrees. The shaded area defines the boundaries of -, from 2% to 15% of the total time of the data run. Significant wave heights are between 1.25 and 2.0 feet.

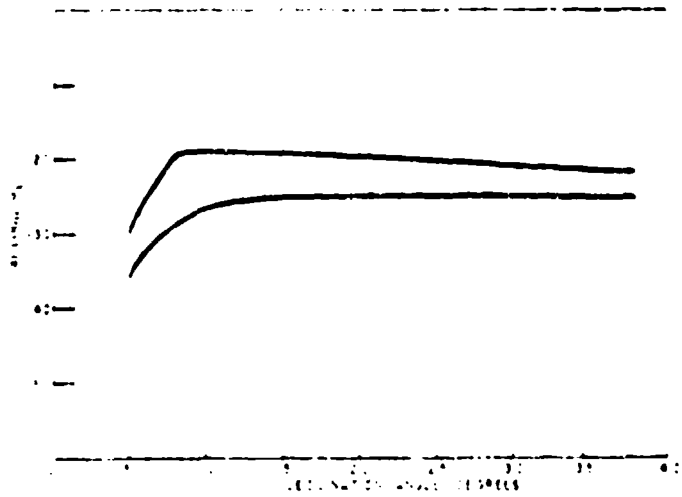


Fig. A1 - Into the waves; polarization vertical, azimuth 150°, wave height 1.75 feet, wind 9-10 knots, 150°

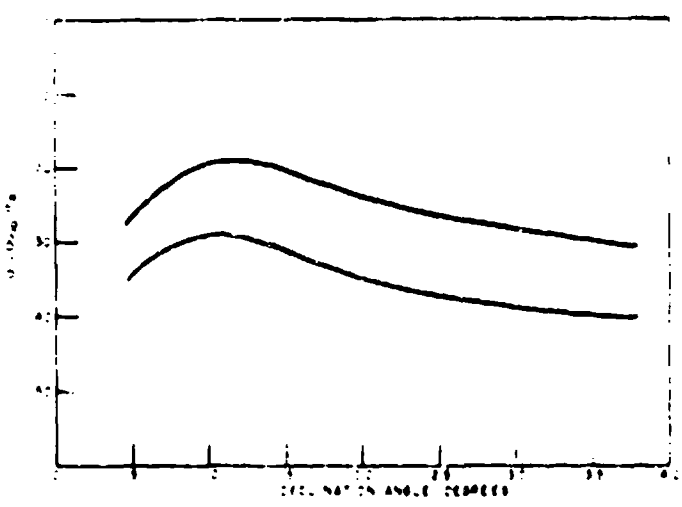


Fig. A2 - Into the waves; polarization horizontal, azimuth 150°, wave height 1.75 to 2.0 feet, wind 9 - 10 knots, 160° - 170°

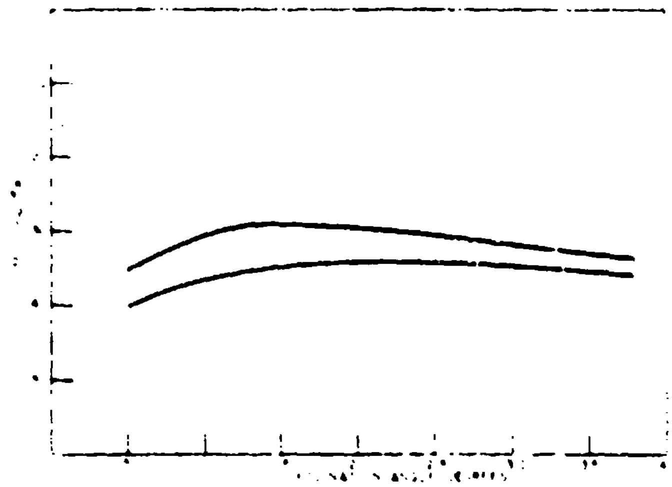


Fig. A3 - Into the trough, polarization vertical, azimuth 45°, wave height 1.75 feet, wind 8-10 knots, 150° - 155°

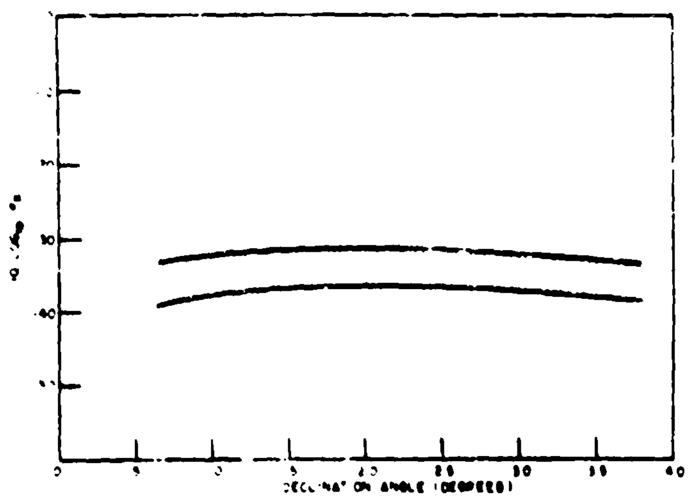


Fig. A4 - Into the trough; polarization horizontal, azimuth 45°, wave height 1.75 to 2.0 feet, wind 9 knots, 160° - 165°

II. [illegible] Versus [illegible] Time

Figures A5 and A6 depict the varia[illegible] various wi[illegible] and horizontal polarizations. The ampli[illegible] versus th[illegible] the radar echo equaled or exceeded a par[illegible]

The data sampled to provide these plots wa[illegible] a height of 90 fe[illegible] water with significant wave heights varying from [illegible] feet. [illegible] looking in the direction of the apparent wave mov[illegible] the cu[illegible] taken at ranges of 450 yards, 500 yards, 1000 ya[illegible] yards, [illegible] yards [illegible] 2500 yards.

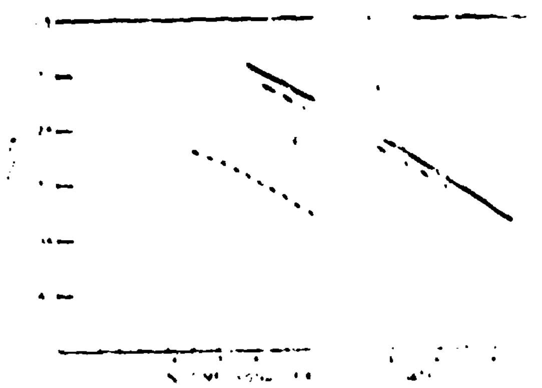


Fig. A5 - Polarization v[illegible] [illegible], azimuth 80° - 90°, wave height 3.[illegible] 3.5 feet, wind 70° - 90°, height 90 feet

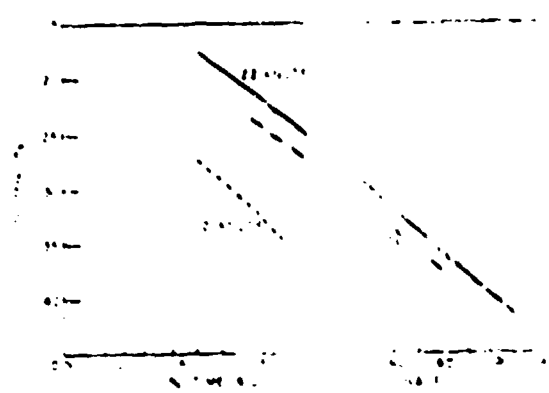
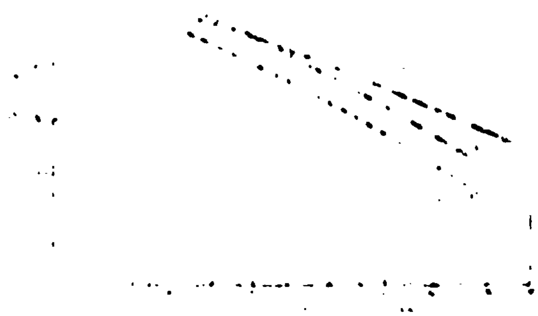


Fig. A6 - Polarization [illegible] [illegible], azimuth 80° - 90°, wave height [illegible] feet, wind 70° - 90°, height 90 feet



[illegible]

[illegible] ... the apparent wave ... Figs. A9 and A10. ... compared ... [illegible] ... at ranges of ... [illegible] ... the wave height varied from 1.75 feet to 2.0 feet.

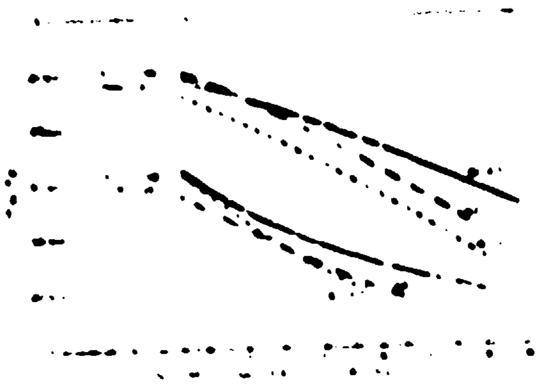


Fig. A9 - Polarization vertical, azimuth [illegible] and 45°, wave height [illegible] 75 feet, [illegible]

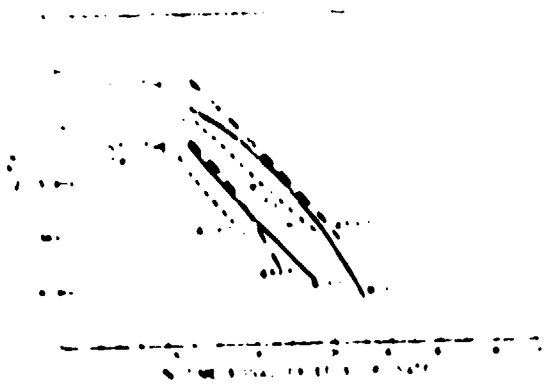


Fig. A10 - Polarization horizontal, azimuth 150° and 45°, wave height 1.75 to 2 [illegible] feet, wind 9 - 10 knots, 150° - 165°

V r_0 Versus α

Figures A11 and A12 depict for vertical and horizontal polarizations r_0 versus the declination angle in degrees as a function of wave height. The curves were plotted from radar echo recurrences of 3% of the total sample. The attitude of the radar antenna was looking in the direction of the apparent wave source and the information used in assembling this graph was taken at heights of 40 feet, 65 feet and 90 feet above average water.

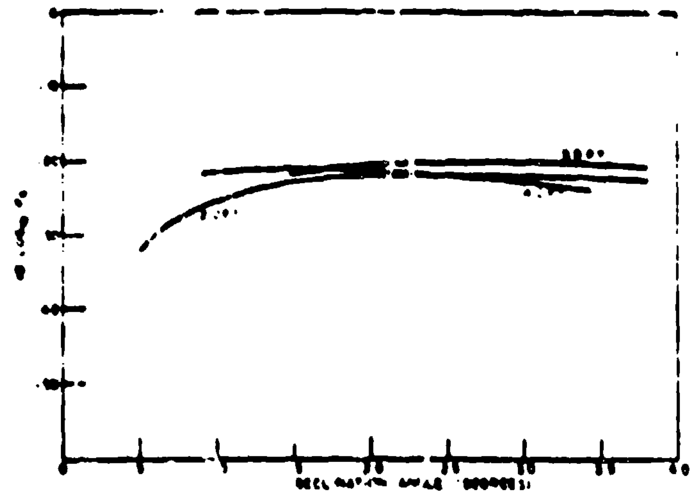


Fig. A11 - Polarization vertical

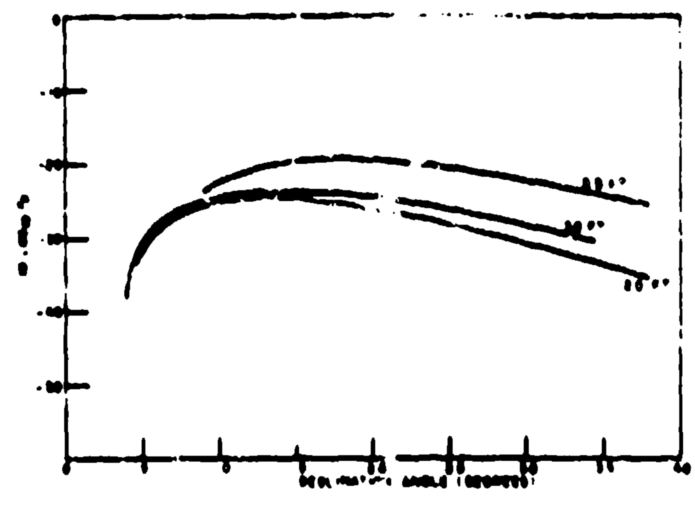


Fig. A12 - Polarization horizontal

[redacted]

VI. $_o$ Versus

Figures A13 and A14 present the $_o$ versus the declination angle in degrees as a function of wind speed in knots for vertical and horizontal polarizations. The curves were drawn from signal recurrences of seven percent of the total sample. The data was assembled at ranges of 500 yards, 1000 yards, and 1500 yards with antenna elevations of 33 feet, 40 feet, 43 feet, 64 feet and 90 feet above average water. The antenna was looking in the direction of the apparent wave source with significant wave heights ranging from 1.75 feet to 3.5 feet.

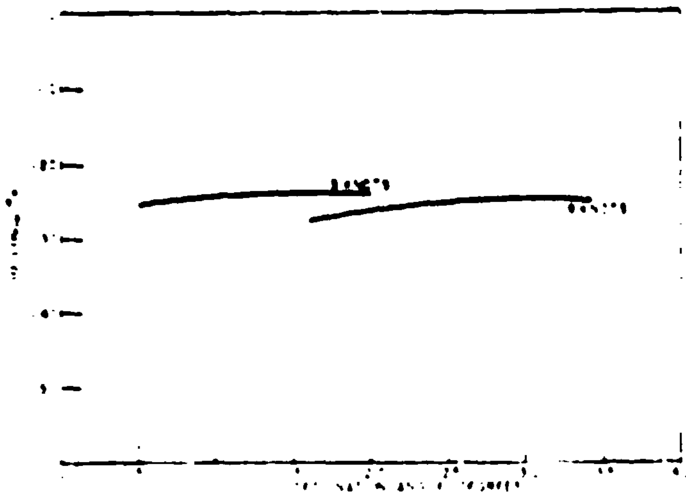


Fig. A13 - Polarization vertical

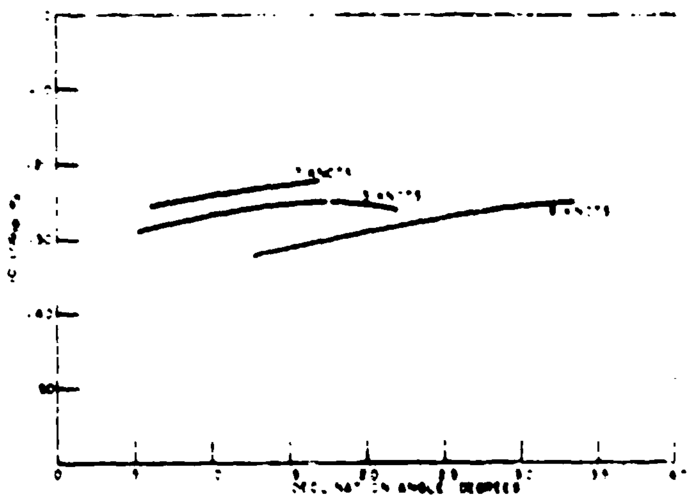


Fig. A14 - Polarization horizontal

[redacted]

VII. Versus Wind Speed

Figures A15 and A16 present the variation of with wind velocity for horizontal and vertical polarizations. The ... here again ... of signal return from 2% to ... of the total time sample. The antenna ... climatic conditions were similar for both polarizations and the data was ... cases from range annulee at 450 yards, 500 yards, 1000 yards, and 2000 yards.

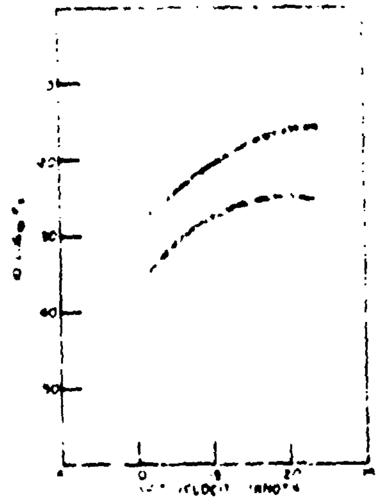


Fig. A15 - Polarization vertical, azimuth 90°, wave height 3.25 to 4.0 feet, wind ... height 90 feet

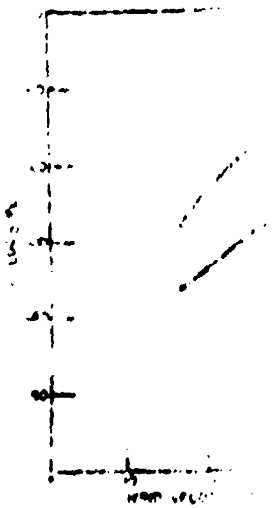


Fig. A16 - Polarization horizontal, azimuth 90°, wave height 3.25 feet, wind 80° - 90°, height ... feet

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1. The subject reports do not contain material which should be restricted under current guidelines. Current investigation into backscatter phenomena of this type are published in the open literature and as NRL publication intended for unlimited distribution. The distribution statement on the subject reports may be changed to allow public release.

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Edward E. Maine
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Acting Associate Superintendent
Radar Division

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